

High-Frequency Acoustics Propagation Effects of Bubbles in Shallow Water

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LONG-TERM GOAL

The long-term goal of this work is to contribute to the understanding of the effects of surf and wind-wave induced bubble fields and their inhomogeneities on the propagation and scattering of sound at high frequencies in shallow water. The ultimate goal of this work is to develop the means of incorporating these effects into acoustic models.

OBJECTIVES

The objectives of this current effort are to identify and describe major alterations in the acoustic fields and signal waveforms caused by the strong and coupled attenuative and dispersive effects of bubbles and to understand their combined effects on acoustic fields to the extent that their waveforms can be predicted in important bubbly environments.

APPROACH

Our approach has been to address several aspects of the effects of bubbles on acoustic propagation in shallow-water environments. We have continued to analyze data taken in earlier experiments, develop tools for studying the relationships between bubble populations and propagation effects, contribute to the planning for a new experiment that was to take place in FY02. That experiment has been postponed indefinitely, and consequently we modified our work during the year. We continued to work with data we collected in 1997 and have furthered our efforts to develop a new mathematical procedure for determining bubble population from attenuation data and sound-speed data.

WORK COMPLETED

We have completed our efforts to extract bubble population from attenuation data from the delta-frame experiment at Scripps Pier. This year such work resulted in a very accurate calculation of bubble population based on our newly extended iterative method for inverting attenuation data, which has been accepted for publication in IEEE J. of Oceanic Eng. We continued to attempt to extract bubble population from sound-speed data. In spite of the fact that we designed the experiment for very precise distance and travel time measurements, our efforts met with only meager success. The problem lay in the fact that accuracy of determining internal locations of the acoustic centers of the hydrophones coupled with an ambiguity in matching the correct cycle of the received signal with a replica created sufficient ambiguity in sound-speed determination. The movement of the water in the path caused by

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ocean waves on the surface and currents was resolved to a large extent, but this coupled with the previously mentioned problems rendered the data inconclusive. It was our plan to resolve some of these problem in the next experiment, but lacking that experiment, we have abandoned the expectation to be able to continue this line of investigation.

In the previous year, we had published a paper on a new iterative technique for solving a set of accurate attenuation measurements for the bubble distribution. As the result of a continued effort this year, we carried the technique out to an arbitrary number of iterations. This has resulted in a recursion relationship that we feel should have wide applications to the inversion of various resonance phenomena. The results of that work has been accepted for publication in the IEEE J. Oceanic Eng. We are investigating the potential of this technique to apply to a wider range of resonance phenomena. A brief review of our new development of the extended iterative technique is summarized in the results section below.

RESULTS

The attenuation coefficient, $\beta(\omega)$, in nepers per meter, for sound propagation through bubbly media is

$$\beta(\omega) = \frac{2\pi c_o}{\omega} \int_0^{\infty} \frac{a \delta n(a) da}{\left(\omega_R^2(a)/\omega^2 - 1\right)^2 + \delta^2}, \quad (1)$$

where c_o is bubble-free sound speed, ω is the angular frequency of the acoustic field, a is the bubble radius, $n(a)da$ is the number of bubbles per unit volume with radii between a and $a+da$, $\omega_R(a)$ is the resonance angular frequency of a bubble with radius a and δ is the damping parameter. For bubbles of radius a there exists a frequency for which the bubbles are resonant, i.e., $f_R(a)$, and there exists an approximation which gives the bubble population in terms of that frequency and the attenuation of a signal at that frequency, viz,

$$n(a) = 4.6 \cdot 10^{-6} f_R^3(a) \beta_m(f_R^3(a)). \quad (2)$$

The procedure involves putting this back into Eq. (1) and making the necessary change in variables and then integration the definite integral. From this we get an approximation value β' for the true β , with the difference easily calculated. This anomalous attenuation ($\beta - \beta'$) could be use in Eq. (2) to approximate the bubble population left out of the first calculation. The results of m iterations of this procedure gives rise to the recursion relationship:

$$n_{m+1} = n_m - 4.6 \cdot 10^{-6} f^3 \beta_m, \quad (3)$$

And, finally

$$\beta \approx \beta_{est} = \sum_{i=0}^m \beta_i \quad \text{and} \quad n \approx n_{est} = \sum_{i=0}^m n_i. \quad (4)$$

The procedure was applied to a simulated population and the results of several iterations are shown in the Figs. (1) and (2).

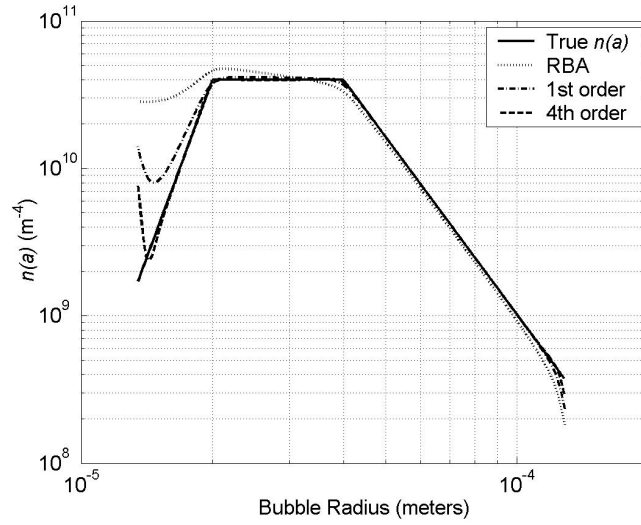


Figure 1: Bubble population density versus bubble radius. [A theoretical, three-part bubble density function was adopted and the iterative corrected densities are shown.]

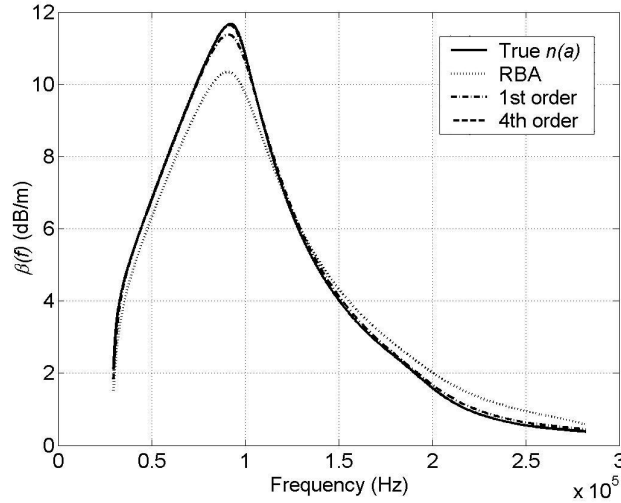


Figure 2: Attenuation versus frequency. [The “true” values are calculated by solving Eq. (1). The iterative corrected attenuations for various orders are shown.]

IMPACT/APPLICATIONS

The work we have been conducting has relevance on several fronts. The attenuation and dispersion analysis and, in particular, waveform analysis should be important to a number of applications, but we should especially highlight its application to underwater communications. The information we developed on the attenuative and dispersive effects of bubble should have application in a number of other underwater acoustics filed as well; in particular, an novel application we developed in the previous year and published this year was for hydrographic surveying. That paper demonstrated that

under certain circumstances bubbles could cause errors in bathymetric measurements that exceed the International Hydrographic Organization standards. We believe that the development of a recursion relationship for the inversion of attenuation data resulting in bubble populations should have a broad application to the inversion of other integral equations representing resonance phenomena. We plan to investigate that potential in the coming year.

TRANSITIONS

Three areas in which transitions may be expected are (a) results waveform analysis and simulation in attenuative, dispersive media should be important in the construction of signals for underwater communications, (b) information on the effects of bubbles on hydrographic surveys should be useful to the hydrography community, and (c) the new iterative technique for the inversion of integral equations describing resonance phenomena should be useful for practical and theoretical analyses in a wide range of resonance phenomena.

RELATED PROJECTS

The ONR bubble project over the last four years have involved a number of investigator teams. The NRL team, including Drs. Steve Stanic, Jerry Caruthers and Ralph Goodman (the latter two now with USM) and several supporting scientists led the overall experiment effort. The NRL team was responsible for planning and coordinating the on-scene work. Investigators having individual experiments within the coordinated effort included several other teams: Drs. David Farmer and Svein Vagle, Drs. Ken Melville and Eric Terrill, Dr. Ming Su and John Cartmill, and Dr. Peter Dahl, as well as a few others not directly connected with the overall experiment. Associated with the work from a theoretical aspect and using data collected by the NRL and other teams was Drs. Frank Henyey, Dan Rouseff, and Steve Kargl. A separate project supported by NRL and conducted by Dr. Guy Norton and Richard Keiffer and a PSI contractor, Dr. Jorge Novarini, is a modeling study involving propagation just below the sea surface with interactions with the sea surface and bubbles. We expect future experiments will provide data relevant to their modeling.

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P.A. Elmore and J.W. Caruthers, "Higher order corrections to an iterative approach for approximating bubble distributions from attenuation measurements," submitted to *J. Acoust. Soc. Am.*

S.M. Sebastian and J.W. Caruthers, "Effects of naturally occurring bubbles on multibeam sonar operations," Proc. of *IEEE Oceans2001*.

PUBLICATIONS

P.A. Elmore and J.W. Caruthers, "Higher order corrections to an iterative approach for approximating

bubble distributions from attenuation measurements,” accepted for publication in *IEEE J. Oceanic Eng.*

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PATENTS

None.